

2) Referring to the top of page 4 of the Office Action of December 8, 1999, the indication of allowable subject matter in claims 6 and 7 is appreciated. Claims 6 and 7 should still be seen as containing allowable subject matter, because the claims have been maintained without amendment. However, for the reasons that will be discussed below, it is respectfully submitted that independent claim 1 and all of the dependent claims also contain allowable subject matter.

3) Before particularly addressing the specific rejections, and comparing the claim features to the disclosures of the prior art references, the invention will be discussed in general terms to provide a background.

Applicants incorporate by reference herein and expressly reassert all of the remarks set forth in the Response dated September 11, 1998. Namely, the general discussion of the invention and the arguments presented with respect to each reference are still pertinent, and the Examiner is respectfully requested to review the prior remarks in the context of the present Office Action.

The most important features of the present invention in contrast to the prior art, will now be discussed in greater detail. In comparison to the prior art, the inventive method uses an entirely different (novel and nonobvious) process or mechanism for introducing and controlling the concentration of carbon as a purposeful dopant into a compound semiconductor melt from which a compound semiconductor crystal is to be grown.

4) As has been pointed out by the Examiner, some prior art crystal growing methods use a softened or melted B₂O₃ substance having a

given concentration of water therein, as a liquid encapsulant to encapsulate the semiconductor melt.

According to the conventional knowledge and understanding in the art, the water content in the B₂O₃ encapsulant expressly provides a gettering effect for removing carbon from the semiconductor melt (see e.g. U. S. Patent 5,131,975 - Bourret-Courchesne at col. 4, lines 55 to 61; col. 6, lines 40 to 53; and Figs. 3A and 3B; and U. S. Patent 5,515,810 - Yamashita at col. 1, lines 15 to 36; col. 3, lines 5 to 10, and 49 to 51; col. 5, lines 1 to 3 and 14 to 16; and col. 8, lines 1, 2 and 46 to 51).

Thus, according to the ordinary level of skill and the conventional understanding in the art, the final concentration of carbon in the semiconductor melt and ultimately in the semiconductor crystal being formed, is inversely related to the amount of water in the B₂O₃ encapsulant. Namely, the water content of the B₂O₃ encapsulant is adjusted or controlled as desired so as to try to remove the proper amount of carbon from the semiconductor melt by the gettering effect. In that context, a higher water content in the liquid encapsulant will result in a lower carbon concentration in the semiconductor melt, while a lower water content in the liquid encapsulant will result in a higher carbon concentration in the semiconductor melt. However, it has been very difficult to precisely and uniformly control the carbon concentration in the conventional manner throughout a crystal growing process, because the gettering effect of the water in the liquid encapsulant diminishes during the process as the amount of carbon gettered into the liquid encapsulant increases, for example, as noted by Yamashita.

- 5) In contrast to the conventional removal of carbon from the semiconductor melt due to the gettering effect of the water in the liquid encapsulant as discussed above, the invention actually uses water in the softened B_2O_3 to facilitate or enable the dissolution of solid carbon into the semiconductor melt via the liquid encapsulant. Namely, when a B_2O_3 liquid encapsulant containing water is used in combination with solid carbon (further in combination with other features of the invention), the water in the liquid encapsulant causes the dissolution reaction of the solid carbon, such that the now-dissolved carbon can be doped from the liquid encapsulant into the semiconductor melt. As a result of using the water in the liquid encapsulant as a pathway or mechanism for dissolving solid carbon into the semiconductor melt, it becomes possible according to the invention to control the carbon concentration resulting in the semiconductor melt by direct relation with the amount of solid carbon that is added into the raw materials placed into the crucible.
- 6) The prior art has not suggested such a mechanism for the dissolution of solid carbon into the semiconductor melt through the water provided in a liquid encapsulant, because it has not suggested the presently claimed combination of features, and especially has not suggested the proper combination of starting materials and processing steps that are necessary for enabling the above discussed dissolution mechanism, as follows.

For example, the present method specifies that the semiconductor raw material placed into the crucible must be a compound semiconductor material, such as a GaAs polycrystalline solid material. Such a compound semiconductor starting material has a relatively high melting temperature and does not melt before

(i.e. at a lower temperature than) the softening of the B_2O_3 liquid encapsulant, which occurs at about $350^\circ C$. Thus, according to the invention, as the crucible containing the various raw materials is heated, the B_2O_3 liquid encapsulant is first softened so that it flows and intermixes with the solid carbon raw material in the crucible. As a result, the solid carbon dissolves in the water in the B_2O_3 encapsulant. Thereafter, the compound semiconductor raw material melts in contact with the softened or melted liquid encapsulant, which already contains the carbon at least partially dissolved therein. As a next step in the mechanism, the carbon that was originally dissolved in the liquid encapsulant then dissolves from the liquid encapsulant into the semiconductor melt. As a result, it is possible according to the invention to control the concentration of carbon dissolved in the semiconductor melt simply by controlling the amount as well as the surface shape and area ratio (e.g. powder, fiber, or bulk) of the solid carbon material introduced into the crucible.

In contrast, prior art methods that do not start with a compound semiconductor raw material or that do not arrange all the raw materials directly in the crucible, cannot achieve the presently discussed dissolution mechanism for the carbon. For example, in prior art methods that begin with separate unitary elemental raw materials, such as elemental Ga and elemental As, the Ga material melts first, at a temperature of about $30^\circ C$, during the initial heating-up phase. The melted Ga flows, contacts and intermixes with the solid carbon (which has not yet been dissolved because the B_2O_3 encapsulant has not yet softened). Since Ga has a superior and preferential wetting characteristic with respect to carbon, the solid carbon is at least

partially covered and surrounded by the melted Ga, which in turn prevents that carbon from being able to react with the water provided in the B_2O_3 encapsulant, even after the temperature has sufficiently increased for the encapsulant to be softened or melted. As a result, the carbon cannot dissolve into the encapsulant in a uniform or predictable manner, and it is not possible to carry out the present method.

It is respectfully submitted that the present invention would not have been obvious to a person of ordinary skill, since there is no suggestion in the art of controlling the carbon concentration in the semiconductor melt by direct relation with the amount or configuration of solid carbon added to a crucible, and since the mechanism for achieving such carbon doping and control of the carbon doping concentration according to the invention is exactly the opposite of the conventional understandings in the art.

- 7) Referring to the bottom of page 2 and top of page 3 of the Office Action, the rejection of claims 1, 2, 3, 19, 20 and 21 as obvious over U. S. Patent 5,131,975 (Bourret-Courchesne) in view of Japanese Patent 01-037833 (Yamamoto et al.) (corresponding to Japanese Patent Laying-Open 64-37833) is respectfully traversed.

Claim 1 is directed to a method of preparing a compound semiconductor crystal that is purposely carbon-doped, comprising steps including placing a compound raw material, solid carbon, and a boron oxide substance into a crucible or boat, followed by heating so as to melt the compound raw material, and then solidifying the melted raw material to grow a carbon-doped compound semiconductor crystal. By these method steps, the solid carbon

raw material is purposely doped into the resulting semiconductor crystal.

It is respectfully submitted that the presently claimed method would not have been obvious from the combined prior art references, for the following reasons.

- 8) As pointed out by the Examiner, the Bourret-Courchesne reference teaches a method of growing a gallium arsenide crystal from a melt that is encapsulated in liquid boric oxide.

To begin the process, solid pieces of boric oxide are intermingled with solid pieces of semiconductor raw material in a crucible. During the initial heating, the boric oxide melts first and rises to the top of the melt as noted by the Examiner. The Examiner further notes that Bourret-Courchesne does not disclose or suggest the addition of a carbon dopant into the melt, and especially by means of placing solid carbon directly into the crucible.

The Examiner turns to Yamamoto et al. for disclosing a method by which carbon can be doped into a semiconductor crystal by adding solid carbon to the crucible as a starting material. However, it is respectfully submitted that a person of ordinary skill in the art would not have been motivated to combine the teachings of the two references as proposed by the Examiner, because of the express teachings contrary to such a proposal in each one of the references.

- 9) Bourret-Courchesne teaches that the boron oxide encapsulant purposely has a water content (especially of at least 600 ppm), for purposely removing carbon and other impurities out of the semiconductor melt due to a gettering effect provided by the

water in the liquid encapsulant (see e.g. col. 4, lines 55 to 61; col. 6, lines 40 to 53). Bourret-Courchesne teaches that carbon is typically inadvertently introduced into the semiconductor melt, for example from the heater or from the quartz tube used as an outer wall of the growth chamber, when a liquid encapsulant is not used. Bourret-Courchesne further expressly explains that the disclosed liquid boron oxide layer encapsulating the semiconductor charge avoids or prevents the introduction of carbon particles and impurities into the semiconductor charge (col. 6, lines 54 to 59), and that the water content of the boron oxide encapsulant will purposely act as a barrier and a getter to exclude carbon and purposely remove carbon that would otherwise end up in the semiconductor melt (see e.g. col. 6, lines 43 to 47).

- 10) In view of the above express teachings of Bourret-Courchesne, a person of ordinary skill in the art reading the Bourret-Courchesne disclosure would have understood that the boron oxide encapsulant containing water expressly prevents and is contrary to the introduction of carbon into the semiconductor melt. Moreover, the water content in the liquid encapsulant will purposely remove any carbon that is introduced into the semiconductor melt. With such an understanding coming from the express teachings of the reference, the person of ordinary skill in the art would not have been motivated to introduce solid carbon directly into the crucible according to Yamamoto et al., because those two teachings would have been directly contrary to each other. It would not have made any sense to a person of ordinary skill in the art to following the teachings of one reference for purposely keeping carbon out of the semiconductor melt and simul-

taneously follow the teachings of another reference to purposely introduce carbon into the melt. There could have been no expectation of achieving a successful result, because the two features or processes in the crucible would have been directly at odds and working against each other.

- 11) As explained by the Examiner, the process according to Bourret-Courchesne is functional as disclosed, because the boric oxide encapsulant melts first and stays on top of the melt, whereafter the remaining solid raw material is melted.

In order to achieve that, it is necessary to start with a compound semiconductor raw material such as GaAs. Such a compound semiconductor raw material has a softening and melting point (e.g. greater than 1200°C for gallium arsenide) that is much higher than the softening and melting temperatures of the boric oxide encapsulant (softening at about 350°C). Therefore, during the initial heating-up of the raw material contents in the crucible, the boric oxide encapsulant will melt first and float to the top as noted by the Examiner.

However, if separate elemental raw materials such as elemental Ga and elemental As are placed into the crucible instead of a compound raw material such as GaAs, then the method according to Bourret-Courchesne will not work. Namely, an elemental raw material such as Ga has a much lower melting temperature (e.g. about 30°C for Ga), so that the Ga melts first during the initial heating-up phase, and prevents the proper sequence of mechanisms as required by the method of Bourret-Courchesne.

On the other hand, Yamamoto et al. expressly teach that separate elemental materials of elemental Ga and elemental As are introduced as the raw materials into the crucible. For the

process of Yamamoto et al., such use of separate elemental raw materials has a purposeful effect in connection with the introduction of solid carbon also into the crucible. Namely, the Ga raw material melts first at a rather low temperature and thus intermixes with and very effectively wets and encapsulates the particles of solid carbon. Thereby, after further heating the carbon can apparently be dissolved directly into the resulting GaAs melt (see e.g. paragraph (1) on page 1 of the partial English translation of the Yamamoto et al. reference).

Therefore, the teachings of the two references are directly contrary to each other or incompatible with each other (and are based on contrary purposes to be achieved). For this reason, a person of ordinary skill in the art reading and understanding the two references would not have been motivated to combine the respective teachings, or to modify the method of either reference to incorporate features from the other, because the teachings are mutually contradictory or would be incompatible in practice.

Namely, if the aim were to dissolve solid carbon into a GaAs melt, then the Yamamoto et al. reference would have suggested that it is necessary to start with separate elemental Ga and elemental As raw materials. On the other hand, if the aim were to properly carry out the encapsulating method of Bourret-Courchesne, then the Bourret-Courchesne reference would have suggested that it is necessary to start with a compound GaAs material in order to be able to achieve the desired self-forming boron oxide encapsulation especially with a water content.

- 12) Moreover, even if the teachings of the two references were somehow combined, the result would not have suggested the present invention. The method taught by Bourret-Courchesne teaches away

from the purposeful doping of carbon into the melt due to the carbon-removing gettering effect of the water in the encapsulant. Thus, to achieve carbon doping, the person of ordinary skill in the art would have understood that the water content in the encapsulant according to Bourret-Courchesne should be avoided if it were considered that the disclosed method could be used at all. Furthermore, if it was intended to add solid carbon into the crucible, the use of separate elemental Ga and elemental As according to Yamamoto et al. would have been necessary to be able to dissolve the carbon into the resulting GaAs melt. Such understandings would have provided a motivation directly away from the combination of reference teachings as proposed by the Examiner, in the first place, and also demonstrate that the proposed combination fails to suggest the invention.

- 13) The dependent claims recite additional features that further distinguish the invention over the prior art. Particularly, claim 2 recites melting the boron oxide substance and having the melted boron oxide substance in contact with at least a portion of the solid carbon while heating and melting the compound raw material. On the one hand, Bourret-Courchesne teaches away from introducing solid carbon into the crucible, and on the other hand Yamamoto teaches the use of separate elemental Ga and elemental As as starting materials, whereby the solid carbon will become at least partially encapsulated by and dissolved into the first-melting Ga. Even viewing these references in combination teaches away from the combination and sequence of steps as recited in present claim 2.

14) For the above reasons, it is respectfully submitted that present claims 1, 2, 3, 19, 20 and 21 would not have been obvious over Bourret-Courchesne in view of Yamamoto, and the Examiner is respectfully requested to withdraw the corresponding rejection under 35 U.S.C. §103.

15) Referring to the middle of page 3 of the Office Action, the rejection of claims 4 and 5 as being obvious over Bourret-Courchesne in view of Yamamoto, and further in view of U. S. Patent 5,515,810 (Yamashita) is respectfully traversed.

Claims 4 and 5 recite that the boron oxide substance according to the present invention comprises boron oxide and water, and particularly 10 to 500 wt. ppm of water.

It is noted that both Bourret-Courchesne and Yamashita disclose the use of a boron oxide encapsulant containing water (and especially at least 600 ppm of water according to Bourret-Courchesne). However, both Bourret-Courchesne and Yamashita expressly teach that the effect of the water in the encapsulant is to remove carbon and other impurities from the melt, due to a gettering effect of the water (see e.g. Bourret-Courchesne, col. 4, lines 55 to 61, and col. 6, lines 40 to 53; and see Yamashita, col. 1, lines 15 to 37; col. 3, lines 5 to 11 and 49 to 51; col. 5, lines 1 to 3, and 14 to 16, and col. 8, lines 1 and 2).

On the other hand, it is noted that Yamamoto et al. (in the method involving the addition of solid carbon directly into a crucible with the raw materials) are silent and do not suggest that the B₂O₃ encapsulant should further contain water.

From these three references in combination, a person of ordinary skill in the art would have understood that the use of

water in a boric oxide encapsulant expressly provides a gettering effect of removing carbon from the semiconductor melt (e.g. according to Bourret-Courchesne or Yamashita), but if the express purpose is to introduce carbon into the melt then there is no suggestion to provide water in the encapsulant (e.g. according to Yamamoto et al.).

For the above reasons, it would not have been obvious to a person of ordinary skill in the art to modify or combine the teachings of the various references as suggested by the Examiner, when the ultimate goal was to purposely introduce solid carbon into the raw materials in the crucible for doping the carbon into the semiconductor melt. The Examiner is respectfully requested to withdraw the rejection of claims 4 and 5 as obvious under 35 U.S.C. §103 over Bourret-Courchesne in view of Yamamoto and Yamashita.

- 16) Referring to the bottom of page 3 of the Office Action, the rejection of claims 8 to 18, 22 and 23 as obvious over Bourret-Courchesne in view of Yamamoto and further in view of Yamashita is respectfully traversed.

Claims 8 and 9 relate to a further processing step of subjecting the solid carbon raw material to a heat treatment under reduced pressure before placing the solid carbon into the crucible. This feature has not been directly addressed by the Examiner. Instead, the Examiner has asserted that the only difference between the combined references and the present invention is "*the type of carbon and melt times*". The additional processing step as presently recited in claims 8 and 9 is nowhere suggested in any of the references. The only reference that suggests placing solid carbon directly into the crucible is Yamamoto

et al., and Yamamoto et al. simply refer to such carbon as a fine powder of high purity carbon, and do not describe pre-processing steps of the carbon as presently claimed.

Claims 12 to 18 recite different forms or surface area configurations of the solid carbon to be introduced into the crucible. As explained in the present specification (see e.g. page 10, line 13 to page 12, line 21), the relative surface area of the solid carbon directly influences the rate at which the carbon is dissolved into the water-containing liquid encapsulant, and thereby directly affects the concentration of carbon in the final semiconductor crystal. Thus, both the amount and the surface area configuration of the carbon are used according to the invention to control the carbon concentration in the final semiconductor crystal. Such control of the carbon concentration is not suggested anywhere in the prior art, and has not been addressed by the Examiner. Instead, as discussed above and as mentioned by the Examiner, the amount of water in the liquid encapsulant has conventionally been used to control the carbon concentration in the semiconductor melt and the semiconductor crystal.

It is noted that claim 22 depends from claim 6, which has been indicated as containing allowable subject matter. Thus, claim 22 should not have been rejected.

Claim 23 recites that the present method is carried out in such a manner so as to achieve a high degree of uniformity in the carbon concentration throughout the resulting semiconductor crystal. According to the prior art, it has been very difficult to achieve acceptable uniformity of the carbon concentration (see e.g. Yamashita). There is no suggestion in the prior art that a method involving direct introduction of solid carbon into the

crucible, and its dissolution into the semiconductor melt, achieves the presently claimed high degree of uniformity of the carbon concentration throughout the entire semiconductor crystal that is being formed.

- 17) For the above reasons, it is respectfully submitted that claims 8 to 18, 22 and 23 would not have been obvious, and the Examiner is respectfully requested to withdraw the corresponding rejection under 35 U.S.C. 103 applying Bourret-Courchesne in view of Yamamoto and Yamashita.

- 18) New claims 24 and 25 have been added to cover more detailed features of the invention. Claim 24 is based on features originally recited in claims 2, 4, 5 and 21, and supported in the disclosure at page 7, lines 1 to 5 and 18 to 24; page 9, lines 20 to 25; page 11, lines 21 to 23; page 15, lines 14 to 16; page 17, line 25 to page 18, line 4; and page 22, lines 7 to 11. Claim 25 is based on the original disclosure at page 7, line 23 and page 23, table 7. Claim 24 is specifically directed to the use of a recited content of water in the boron oxide encapsulant, so as to carry out the above discussed mechanism of dissolving the solid carbon into the water of the boron oxide encapsulant and then dissolving the carbon from the encapsulant into the melted compound raw material. Claim 25 places an upper limit of 300 ppm on the water in the encapsulant (compare Bourret-Courchesne). In view of the above discussion of the references, it is respectfully submitted that these features of claims 24 and 25 expressly distinguish the invention over the prior art. Entry and consideration of claims 24 and 25 is respectfully requested.

.19) Favorable reconsideration and allowance of the application,
including present claims 1 to 25 are respectfully requested.

Respectfully submitted,

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